

# The LEAP Gamma-Ray Burst Polarimeter for the International Space Station

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- Background
- Introduction to LEAP – LargE Area burst Polarimeter
- Simulation and beam experiments
- Considerations for the ISS
- Future work

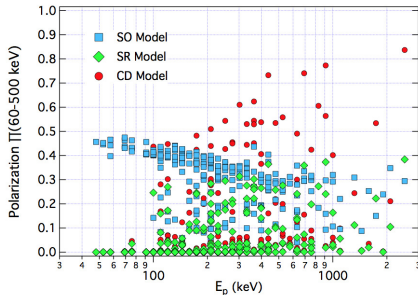
# Gamma-Ray Bursts

- Why measure linear polarization of GRBs?
  - To improve our understanding of GRB jets: their geometry, magnetic field, and radiation mechanism

Polarization parameters observed from a large sample of GRBs depend on the structure of the jet magnetic field (ordered versus random) and emission mechanism

GRB models:

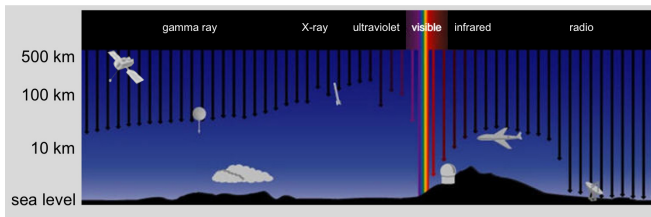
- Synchrotron emission from an ordered magnetic field (SO)
- Synchrotron emission from a random magnetic field (SR)
- Inverse Compton emission from a random magnetic field (CD)



Expected distribution of polarization levels that could be measured as a function of the characteristic peak energy ( $E_p$ ) spectral parameter

# Experimental Challenges

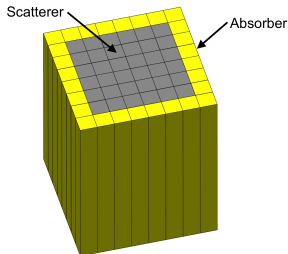
- Models can be distinguished by observing a large sample of GRBs and measuring the fraction displaying significant polarization
- Challenges:
  - GRBs occur randomly in the sky – need wide field of view
  - Need the GRB location to reconstruct the polarization
  - Prompt X-ray emission only lasts a few milliseconds to several minutes
  - X-ray background can mask the polarization signal
  - Need to resolve polarization as a function of time and energy
  - X-rays are absorbed by the atmosphere



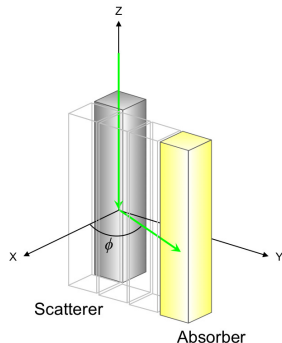


# Compton Scattering Polarimeter

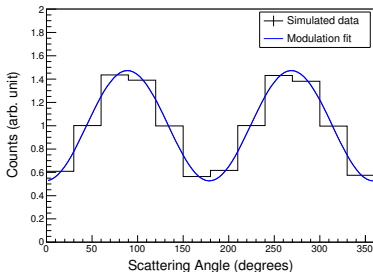
- Two basic components:
  - Low-Z scattering detector
    - Compton scattering medium
  - High-Z absorbing detector
    - Absorbs full energy of scattered X-rays



- The relative positions of the detectors defines the scattering geometry and permits a measurement of the azimuthal scatter angle ( $\phi$ )



# Compton Scattering Polarimeter



- The modulation pattern can be fit with the function:

$$C(\phi) = A \cos \left[ 2 \left( \phi - \phi_0 + \frac{\pi}{2} \right) \right] + B$$

where  $\phi_0$  is the polarization angle of the incident photons

- The polarization modulation factor,  $M$ , is defined as:

$$M = \frac{A}{B}$$

where: A and B are constants used in the fit

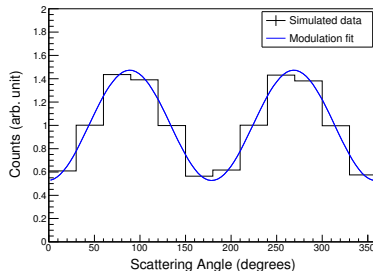
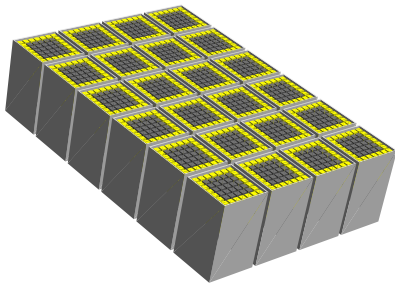
- The polarization,  $\Pi$ , is given as:

$$\Pi = \frac{M}{M_{100}}$$

where:  $M_{100}$  is the modulation for the 100% polarization case and  $M$  is that of the measurement

# Compton Scattering Polarimeter

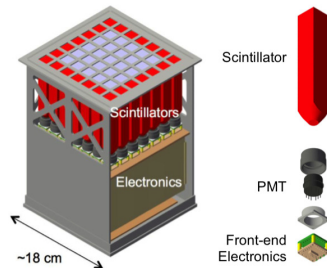
- The most important factors to consider when designing a scattering polarimeter:
  - (1) Scatter as large a fraction of the incident flux as possible while avoiding multiple scatterings
  - (2) Achieve as large a modulation factor as possible
  - (3) Collect as many of the scattered X-rays as possible
  - (4) Minimize the detector background



*M. C. Weisskopf. X-ray polarimetry: historical remarks and other considerations, 2010.*

# LargE Area burst Polarimeter (LEAP)

- Concept for upcoming NASA Astrophysics Explorer Mission of Opportunity proposal
- Designed to mount to the ISS as an external payload
- Wide FoV, Compton scattering-type polarimeter, with GRB localization capability
- Energy range: 50 – 300 keV
- Sensitive detector area  $\approx 3400 \text{ cm}^2$
- 24 Modules – single unit:  
 $\approx 18 \text{ cm} \times 18 \text{ cm} \times 25 \text{ cm}$  (L $\times$ W $\times$ H)
- University of New Hampshire – POET polarimeter module design



- International collaboration:



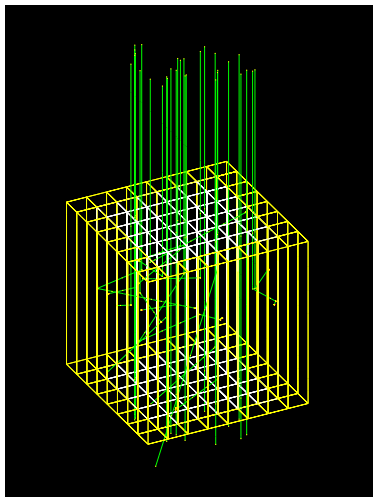
# LEAP Collaboration

Role	Name	Affiliation
Principal Investigator	Mark McConnell	University of New Hampshire
Deputy PI/Institutional PI	Jessica Gaskin	NASA/MSFC
Institutional PI	Shuichi Gunji	Yamagata University
Project Manager	Steven Pavelitz	NASA/MSFC
Project Scientist	Colleen Wilson-Hodge	NASA/MSFC
Principal Systems Engineer	Deborah Kromis	NASA/MSFC
Instrument Manager	John Macri	University of New Hampshire
Science Operations	Mark Chutter	University of New Hampshire
Science Team	Peter Bloser	University of New Hampshire
	Joseph Dwyer	University of New Hampshire
	Jason Legere	University of New Hampshire
	James Ryan	University of New Hampshire
	Robert Preece	University of Alabama Huntsville
	Stephen Daigle	NPP/MSFC
	Douglas Swartz	USRA
	Takeshi Nakamori	Yamagata University
	Tatehiro Mihara	RIKEN



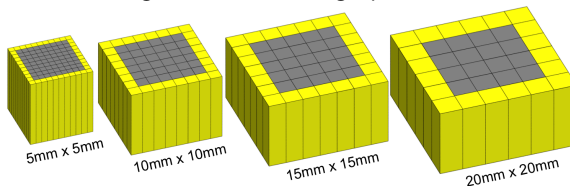
# Simulation

- Polarimeter is modeled using the Geant4 Monte Carlo simulation toolkit
  - GEometry ANd Tracking
  - C++, object-oriented environment
  - Applications: high energy and nuclear physics, astrophysics, space engineering, medical physics, and material science
- Simulation input
  - Detector geometry and materials
  - Energy, direction, and polarization of incident gamma rays
- Simulation output
  - Energy and position of hits
  - Detection efficiency
  - Modulation curve



# Simulation

- Modeled the effect of segmentation on a single polarimeter module

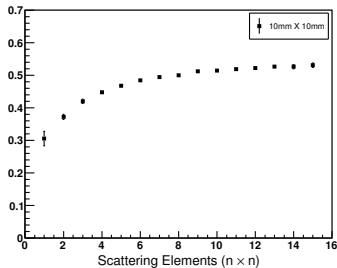


- Square pixels arranged in an  $n \times n$  scattering matrix
- Simulated unpolarized and 100% polarized gamma rays
- Incident gamma-ray energy was stepped over 25 – 500 keV
- Examined:
  - Modulation factor
  - Coincidence detection efficiency

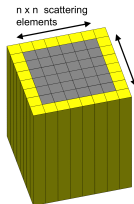
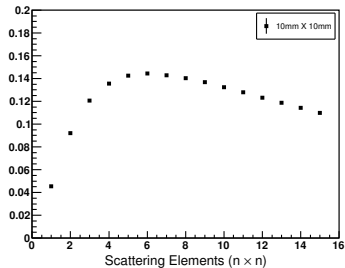
Optimum area of scatterer is determined by the scattering length of gamma rays

# Simulation

Modulation Factor ( $M$ )



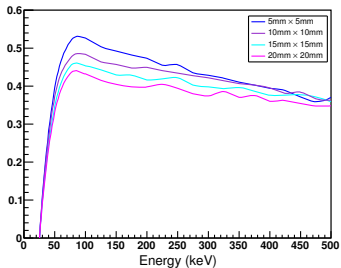
Coincidence Efficiency ( $\eta$ )



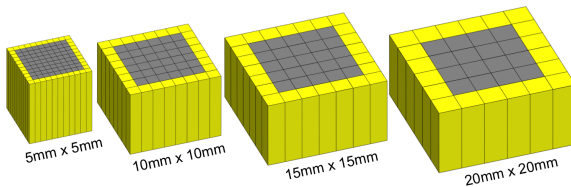
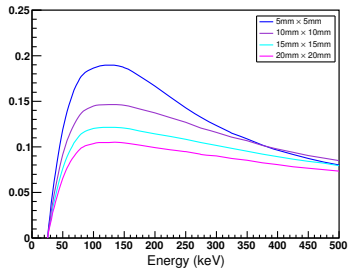


# Simulation

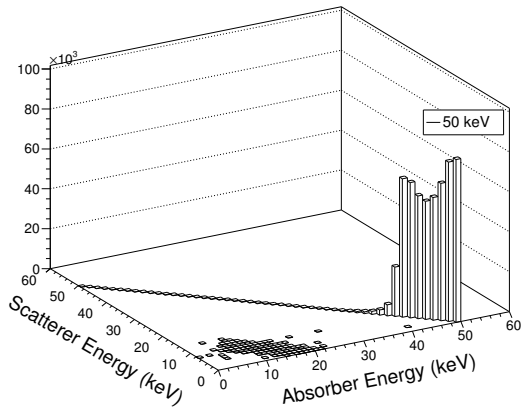
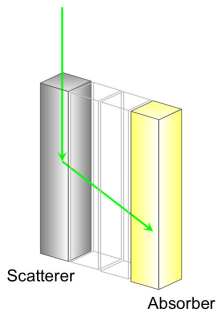
Modulation Factor ( $M$ )



Coincidence Efficiency ( $\eta$ )



# Simulation

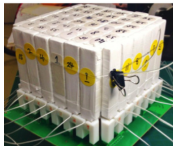
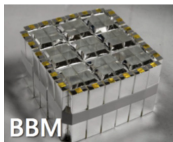


Gamma rays deposit only a few keV in scatterer, majority of the energy in absorber

- Coincidence efficiency is sensitive to low-energy thresholds of detectors

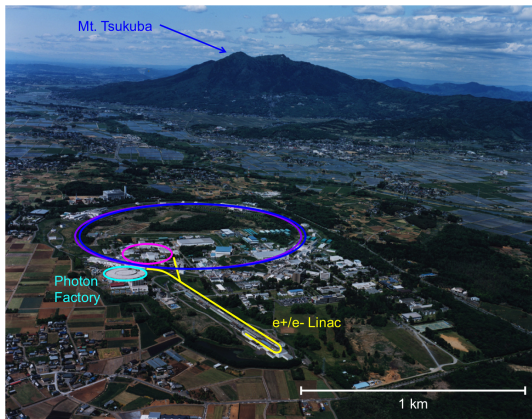
# Beam Experiments

Shuichi Gunji and collaborators at Yamagata University, constructed a breadboard model of the polarimeter module

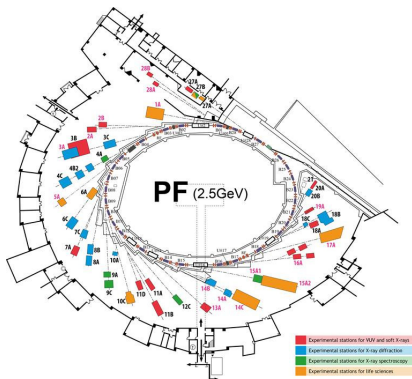


# Beam Experiments

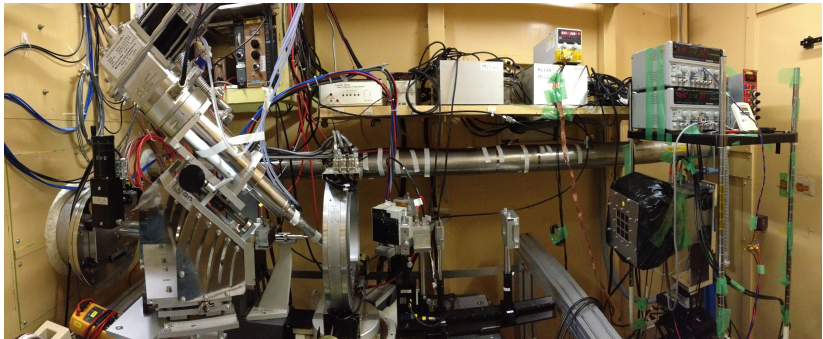
The High Energy Accelerator Research Organization known as KEK, (Kō Enerugi Kasokuki Kenkyū Kikō), in Tsukuba, Japan



# Beam Experiments

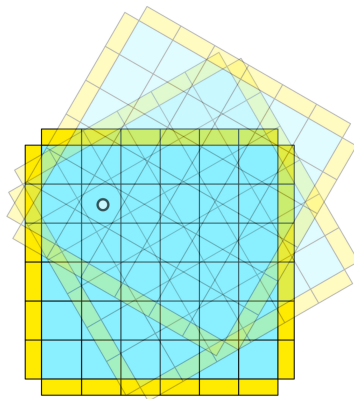


## A look inside the experimental hutch



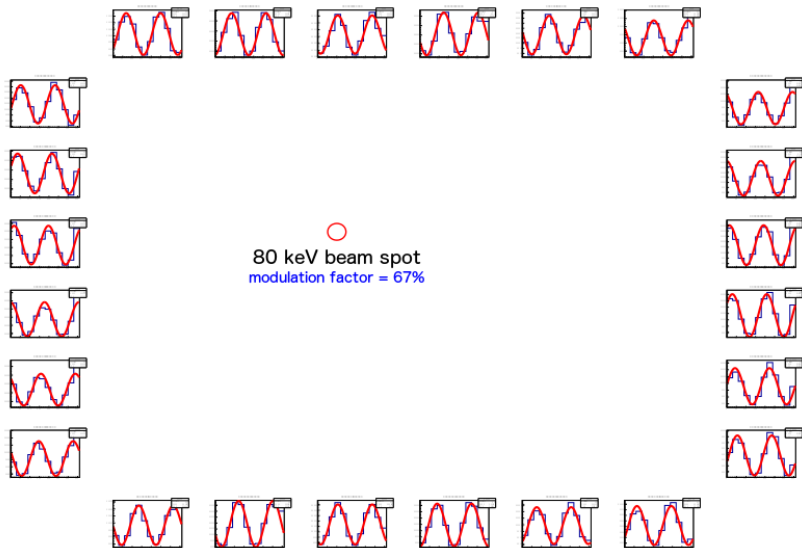
# Beam Experiments

- Irradiate single plastic element with linearly polarized beam
  - Beam spot:  $\approx 1$  mm dia.
  - Energy: 60 keV, 80 keV
- Rotate polarimeter through  $360^\circ$ 
  - $30^\circ$  increments
- Pitch  $30^\circ$  with respect to the beam direction, repeat measurements



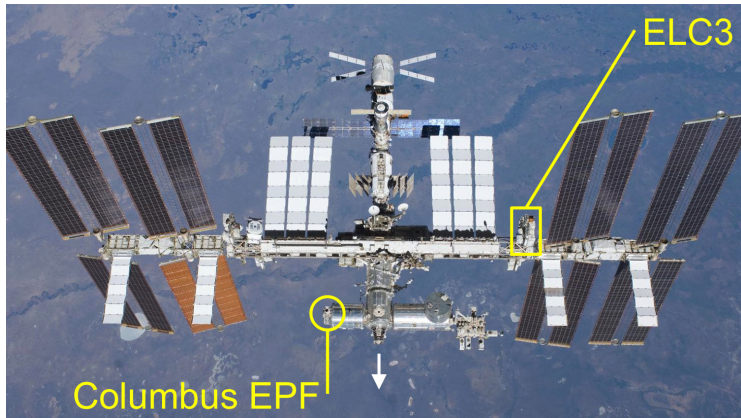
Result: Modulation factor and detection efficiency agree with Geant4 simulation

# Preliminary Results





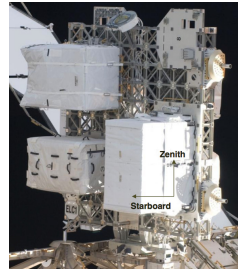
# ISS Accommodations



- EXPRESS Logistics Carriers (ELC)
- Columbus External Payload Facility (Columbus EPF)

- EXPRESS Logistics Carriers

- ELCs are external pallets
- 4 ELCs: 2 starboard/2 port truss
- Sites available per ELC: 2
- 2 ELCs have zenith payload sites
- Mass capacity: 227 kg
- Volume: 1 m<sup>3</sup>

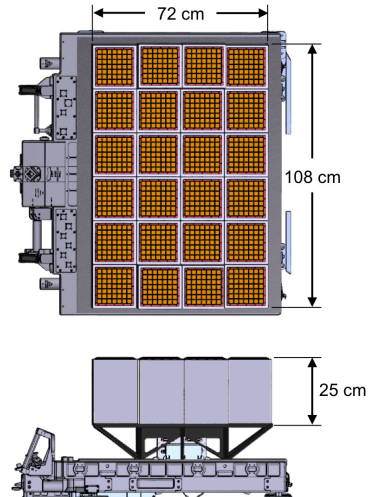
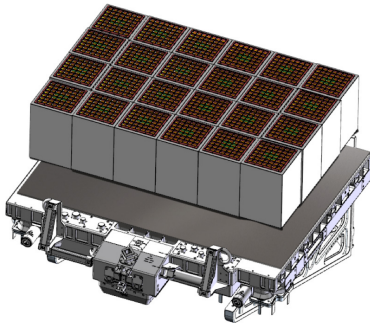


- Columbus External Payload Facility

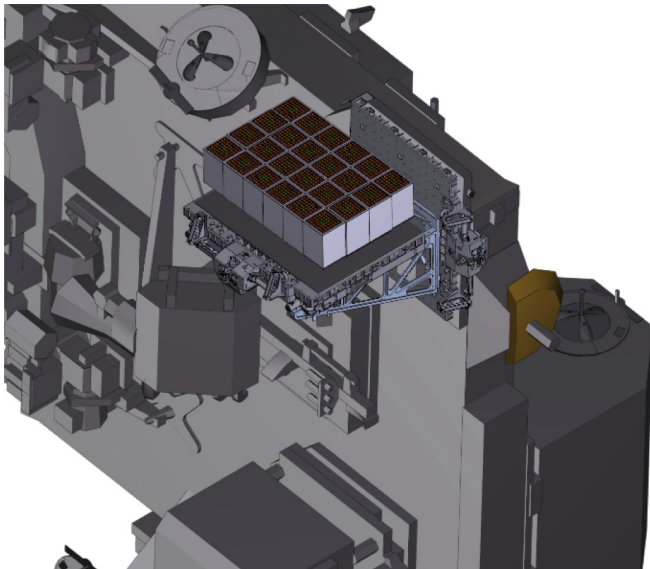
- 2 sites available to NASA
- 1 site is zenith pointing
- Mass capacity: 227 kg
- Volume: 1 m<sup>3</sup>



# LEAP Instrument



# ELC3 Configuration



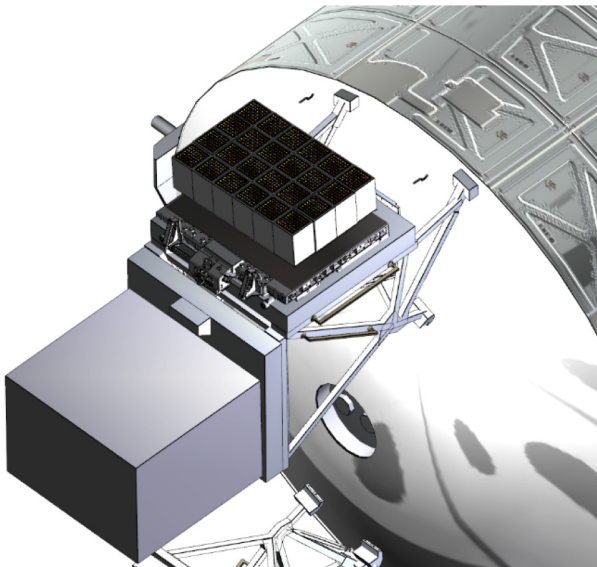
*Mike Baysinger, NASA MSFC Advanced Concepts Office*

Stephen Daigle

LEAP for the ISS

24/30

# Columbus Configuration



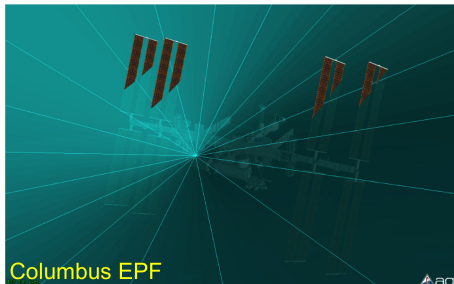
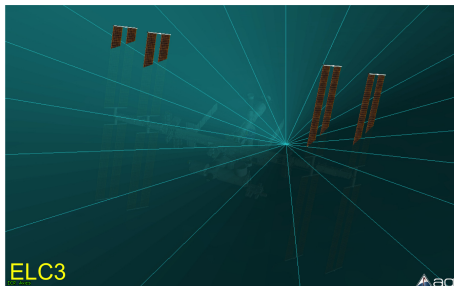
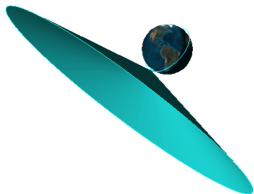
*Mike Baysinger, NASA MSFC Advanced Concepts Office*

Stephen Daigle

LEAP for the ISS

25/30

# LEAP Field of View

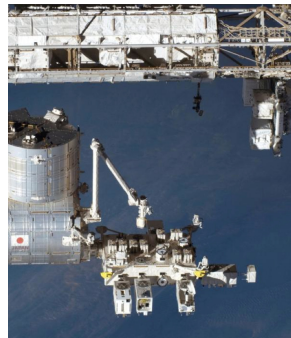


Randy Hopkins, NASA MSFC Advanced Concepts Office

# ISS Radiation Environment

JEM Exposed Facility (EF) payloads that can measure ISS radiation environment:

- Space Environment Data Acquisition equipment (SEDA-AP)
  - Neutrons
- Monitor of All-sky X-ray Image (MAXI)
  - X-rays
- CALorimetric Electron Telescope (CALET)
  - Gamma rays and charged-particles



MAXI found background rates dropped to almost half for a few weeks at a time

- The events correlated with the absence of the Russian Soyuz spacecraft

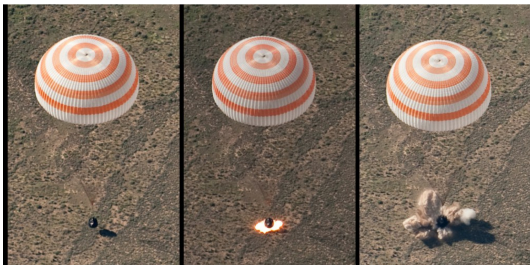
<http://iss.jaxa.jp/en/kiboexp/ef/>

T. Mihara, et al. *MAXI: all-sky observation from the International Space Station*, arXiv, 2014.

# ISS Radiation Environment

- Soyuz has a gamma-ray altimeter used for landing
  - Kaktus provides a “soft landing”
- Ignites inverse rocket at  $\approx 1.5$  m above the ground
- Heat-resistant and shock-proof
- Works over water, ice, snow or firm ground, for any spacecraft attitude and horizontal speed
- $^{137}\text{Cs}$  and  $^{60}\text{Co}$  sources  $\approx 2.5$  Ci

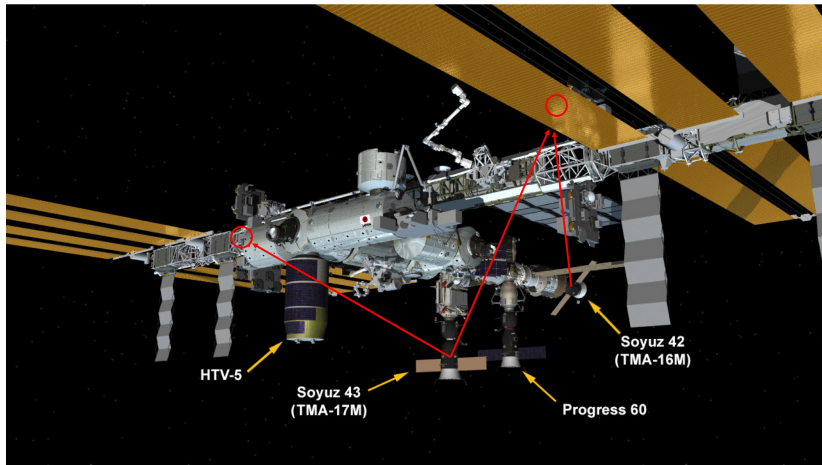
gamma-ray altimeter



Tatehiro Mihara, MAXI team, RIKEN  
<http://www.spacesafetymagazine.com>



# ISS Radiation Environment



- Measuring GRB polarization could help to validate or exclude several theoretical models
  - Provide a better understanding of GRB radiation mechanism and magnetic field
- LEAP is a GRB polarimeter concept for the ISS
  - Proposal for upcoming NASA Astrophysics Explorer Mission of Opportunity
  - International collaboration: NASA MSFC, UNH, UAH, Yamagata University, along with other institutes in Japan
  - Wide FoV, Compton scattering-type polarimeter, energy range: 50 – 300 keV
  - Modular design, sensitive detector area  $\approx 3400 \text{ cm}^2$
  - MSFC Advanced Concepts is assisting with the development
- The `Geant4` Monte Carlo simulation toolkit is used to model the polarimeter
  - Understand polarimeter response and detector background
  - Optimize shielding for ISS radiation environment